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Modelling of hydrodynamic and wave conditions for a new harbor in Søndre Strømfjord (Kangerlussuaq)

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Introduction

Søndre Strømfjord (Kangerlussuaq fjord) is located at the West coast of Greenland, Figure 1. There are three large river systems which transport glacial sediments into the fjord, i.e. the Watson River, Umivit River and Sarfartoq River. The Watson River enters the fjord at the North Eastern head and a well-developed delta is found at its outlet. The existing harbour in Kangerlussuaq is located at this outlet and experiences major sedimentation problems. Deposited sediments have reduced the water depth and hinders cruise- and large container ships from entering the harbour. In order to enter the port, small vessels transport passengers and cargo from the ships which are anchored further out in the fjord. The result is an inefficient operation and high maintenance cost for the municipality. Therefore, a new harbour location was proposed by Stenstad et al. (2015) 10 km further out the fjord near Hancock Pynt (HP), see Figure 1. The new location was selected based on seismic data and it was found that the onshore area is well suited for a harbour support area. The offshore sediments are mainly fine grained and not suitable as support for foundations. In addition, to reach the required water depth a significant amount of sediments need to be removed. The focus of this paper is to set up numerical models of the fjord system and provide the hydrodynamic, wind and wave conditions for the new proposed harbour location.

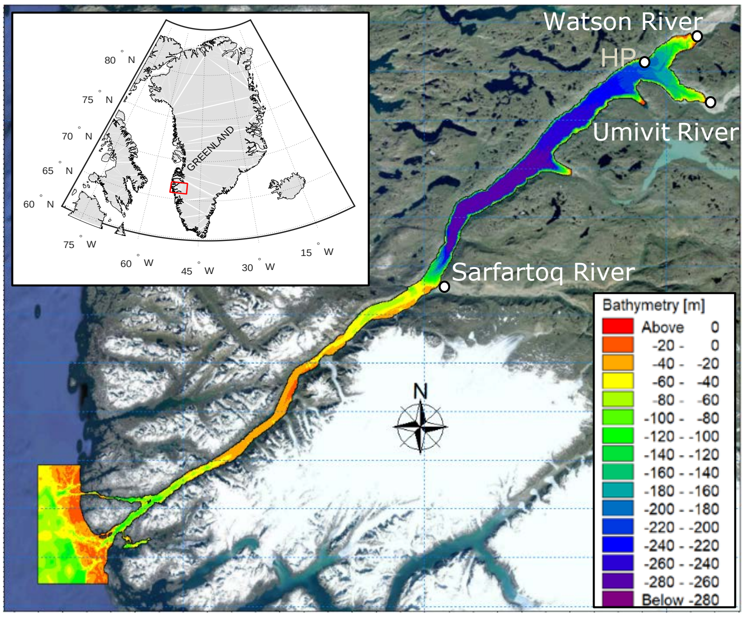

Figure 1. Top left figure is an overview map of Greenland showing the extent of the main map of Kangerlussuaq fjord. The bathymetry of the fjord is shown with a colour code which is also the model extent used in MIKE 21 FM. The new proposed harbour location Hancock Pynt (HP) and the three main rivers are indicated with white circles.

Regional Settings

Kangerlussuaq fjord is roughly 180 km long and has two distinct parts: the inner part which is broad (4-6 km) and deep (up to 280 m), and the shallow outer part which is roughly 100 km long, about 1 km wide and has a depth of 20-80 m. This shallow outer part is unusual for Arctic fjords because of its length and causes the water mass in the inner deep part of the fjord to be almost decoupled from the open ocean (Nielsen et al., 2010). The initial formation of ice in the inner part of the fjord system generally starts at the end of November. The sea ice expands all the way to the outer part of the fjord, close to Sarfartoq River, where the tidal currents are too strong for sea ice to form. In the inner part of the fjord, the sea ice reaches a thickness of about 1 m (Nielsen et al., 2010). An analysis of MODIS images show that at the end of May the last ice floats melt and open water is expected. The ice free period extents from the beginning of June till the end of November.

Approach

Two different numerical models were set up of the fjord system using the MIKE 21 software developed by DHI. The first numerical model is the MIKE 21 Flow Model hydrodynamic module. It simulates water level and flow variations by solving the depth-integrated incompressible Reynolds averaged Navier-Stokes equations (DHI, 2016). The fjord was surveyed by the Danish Geodata Agency in the summer of 2012 and the model bathymetry (Figure 1) was constructed from this data. The computational mesh has a resolution of 440 m outside the fjord and 300 m inside the fjord. There are three open boundaries located outside the fjord. The tides at these boundaries were predicted from a tidal constituents map constructed from the DTU global tide model (Cheng and Andersen, 2010). It includes 10 tidal constituents and has a resolution of 0.125 degrees. The model was calibrated against water level measurements which were collected in the summer of 2011 at multiple locations throughout the fjord. The main calibration parameter is the bed friction and the best fit was obtained by applying a varying Manning number depending on the water depth. The second numerical model is the MIKE 21 Spectral Wave (SW) module. It is a spectral-wind wave model and is able to simulate growth, decay and the transformation of wind-generated and swell waves. The model extent only covers the inner part of the fjord until Sarfartoq River. A computational mesh with resolution of 300 m was used and the model does not include any open boundaries. The wind input was obtained at Kangerlussuaq airport from 1976-2016 (Cappellen, 2017) and was adjusted for height and location. The model was calibrated against wave height measurements at a location close to Hancock Pynt for the period September-October 2013. The main calibration parameter was the type of air-sea interaction, i.e. how the momentum is transferred from the wind to the waves. The 'uncoupled' formulation, where the momentum transfer solely depends on the wind speed resulted in the best calibrated model. An extreme value analysis was performed on the wind data in order to find the wind speed with a return period of 50 years. This was done for two different sectors with the largest fetch, South-West and South-East. The obtained wind speed for each sector was used as input for the MIKE 21 SW model to find the corresponding wave height and peak period.

Results and conclusions

The hydrodynamic, wind and wave conditions found by analysing the wind data and from the numerical model simulations are summarised in Table 1. The tidal wave takes 3.5 hours to travel from the beginning of the fjord to Hancock Pynt. At Hanock Pynt there is a mean spring tidal range of about 3.5 meter and therefore it has a meso-tidal regime (mean spring tidal range between 2-4 meters). The tidal character can be determined from the four major tidal constituents which are at Hancock Pynt: K1 = 0.2575, O1 = 0.1252, M2 = 1.1935 and S2 = 0.3358. The form factor, F = (K1+1)/(M2+S2), is used to classify the tidal characteristics and has a value of 0.2503. Hence, the tide is mixed, mainly semidiurnal. The maximum flood current speed observed is 0.2 m/s and the maximum ebb current speed is 0.148 m/s. The 50 year return period wind speed, wave height and peak wave period for the South-West and South-East sector are shown in Table 1. It can be seen that the wave height coming in from the South-West is larger than the one coming in from the South-East. Though, the waves from both directions should be taken into account when designing the layout of the harbour. Beside the wind, current and wave conditions which are provided in this paper, further investigations regarding the ice forces and sediment transport are needed in order to come up with a suitable harbour design. Currently, a MIKE 3 model is under construction which will give a more detailed picture of the (3D) current field in the fjord.

Table 1. Wind, wave and hydrodynamic conditions at Hancock Pynt.

Parameter	Value	Unit
Lowest astronomical tide (LAT)	-1.74	m
Highest astronomical tide (HAT)	1.89	m
Maximum tidal current speed	0.2	m/s
50 year return period wind speed (South-West)	16.5	m/s
50 year return period wave height (South-West)	1.8	m
50 year return period peak wave period (South-West)	5	s
50 year return period wind speed (South-East)	16.1	m/s
50 year return period wave height (South-East)	1.18	m
50 year return period peak wave period (South-East)	3.95	s

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